# PXIE Vacuum Considerations

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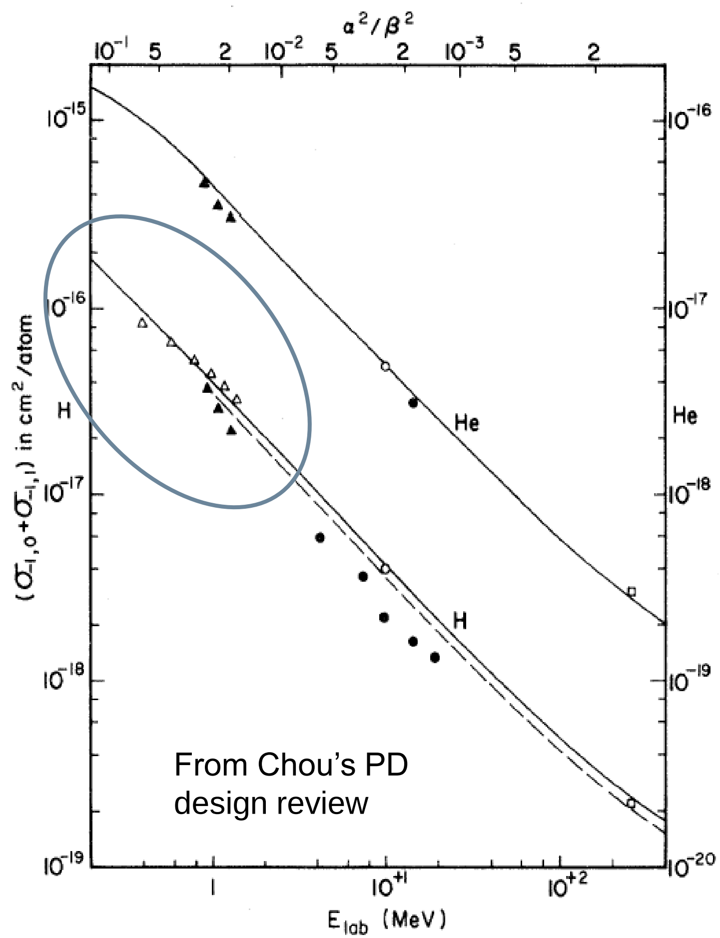
# Motivation

- Establishing communication with entire project about vacuum requirement, we all live together in the vacuum environment
- Integrate vacuum requirement in machine design, key component design, instrument design, to reduce the likelihood of problems late, such as material choices compatible with UHV and low particulate requirements
- Lesson learned from HINS RFQ
  - Thorough leak check during the steps of construction of component
  - Improper vacuum seal method
  - Need of vacuum person get involved at the design stage of project

# the Vacuum Requirement of PXIE

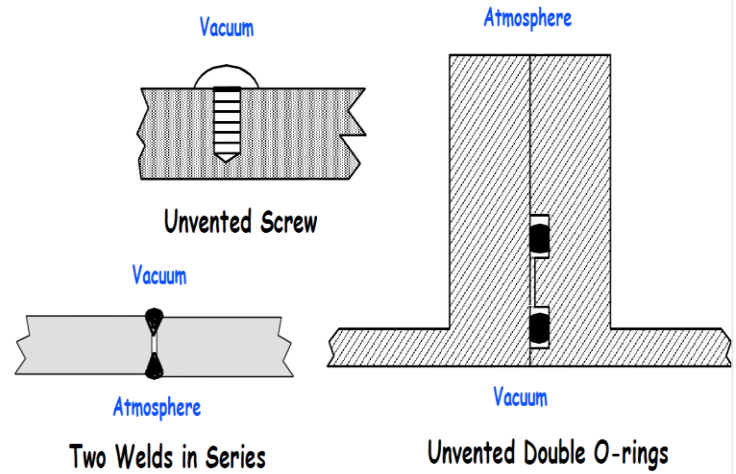
- Residual gas pressure?
  - driven by reasonable beam loss due to beam-gas interaction or required by specific instrument in order function properly
- Gas species sensitive?
  - $H_2$, $N_2$, $H_2O$, Ar, $CO_{2,}$ hydrocarbons
- Particle count for SRF?
  - class 1, 10, 100, 1000,…
- Contamination control:
  - segmentation, migration, locations of pumping, venting
- Real-time monitoring
  - pressure gauges, pump status, partial pressure ratio(RGA)



# the Vacuum Requirement of PXIE

- Materials used in vacuum
  - Outgassing (rate and species)?
  - Producing particles?
- Design
  - Vacuum Seal design: brazing, welding, or flanged(metal or O-ring)
  - Avoiding virtual leak: blind screw; double joint; …
- Procedures for QC:
  - Machining: cutting fluids …
  - Cleaning: material specific, Cu, SS, Al, …
  - Handling: groves, foils, tools, clean area,
  - Thorough leak check before major steps
  - Certified before installation in the system
- Management Policy
  - vacuum experts shall involved in major design reviews

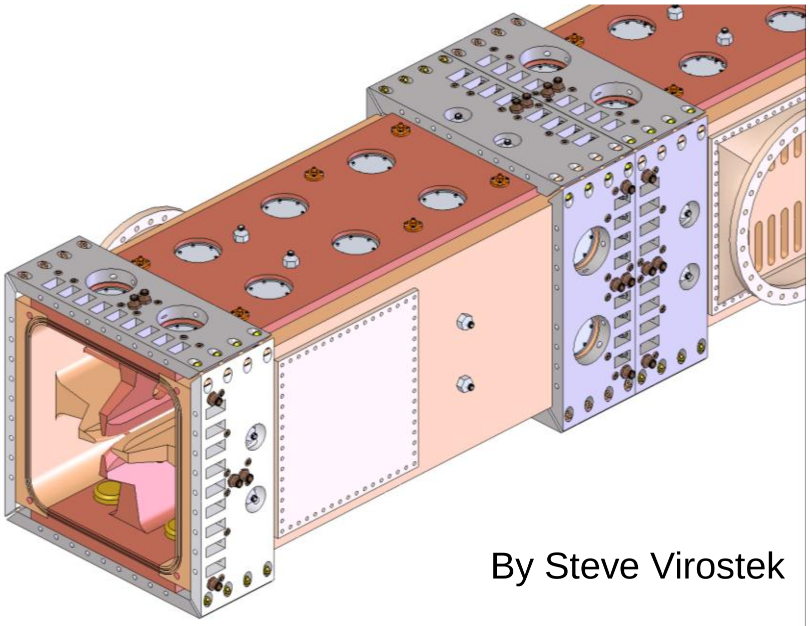
A virtual leak is a volume of trapped atmospheric gas that leaks into the vacuum vessel through holes or cracks that do not go all the way through the vessel wall.




**Accelerator Vacuum Engineering**
**By Louis R. Bertolini, LLNL**

# Gas loads in PXIE

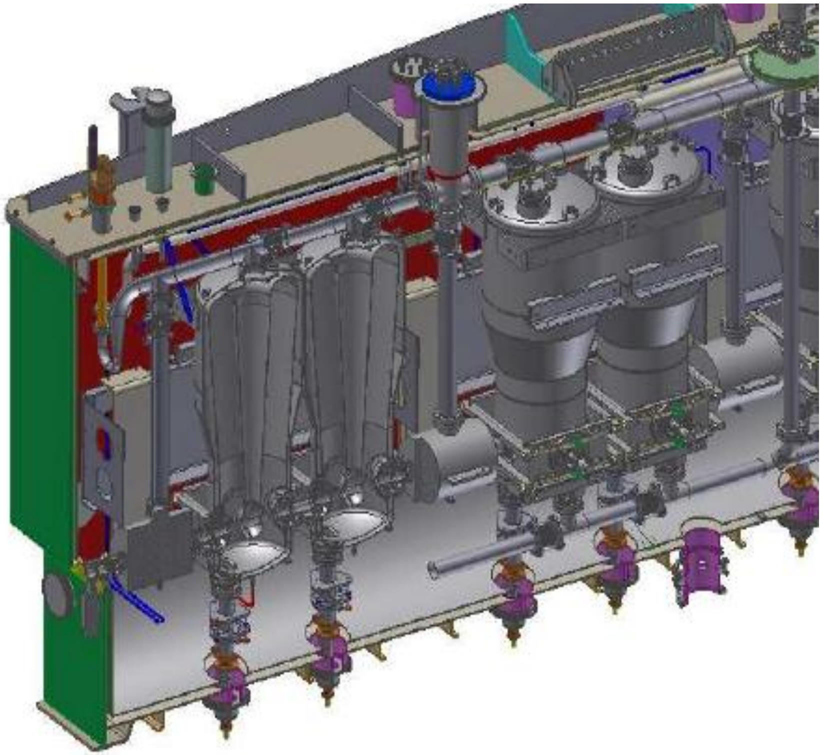
- $H^-$ Ion source (~$10^{-1}$ torr.l/s)
  - $H_2$ introduce by pulse valve, in order to make $H^-$
  - maintain proper pressure, ~$10^{-5}$ torr
- RFQ (~$10^{-5}$ torr.l/s)
  - permeation thru O-rings, ~$10^{-6}$ torr.l/s
  - surface outgassing, ~$10^{-6}$ torr.l/s
  - gas flows from LEBT, ~$10^{-6}$ torr.l/s
  - Beam neutralization, ~$10^{-5}$ torr.l/s
- MEBT (~$10^{-4}$ torr.l/s) and Diagnosis lines and beam dump
  - significant $H_2$ production from absorber, ~$10^{-4}$ torr.l/s
  - outgassing from every devices exposed in vacuum, such as cavities, beamtubes, beam instrumention… ~$10^{-5}$ torr.l/s
- Cryomodules
  - Insulating vacuum: large and dirty, but low requirement
  - Coupler vacuum: not significant
  - Vaporization from condensation due to temperature rise( sensitive)
  - Cavity vacuum: from warm section, depends on pressure and conductance



By Steve Virostek

# Gas loads in PXIE

- Without DP between MEBT and CM
  - $H_2$ due to 10mA beam neutralized at absorber Q=9.6E-4 torr.l/s
  - assume 3000 l/s effective pumping
  - Pressure at Absorber: P=3.2E-7 torr
  - Aperture of beamtube: d=1.37”
  - Distance of absorber to CM: L=2.5m
  - Flux to CM: Q=2.4E-6 torr.l/s
  - d1=40mm, l1=400mm
  - One monolayer time: 1.8 hours
  - Then the CM get flooded quickly



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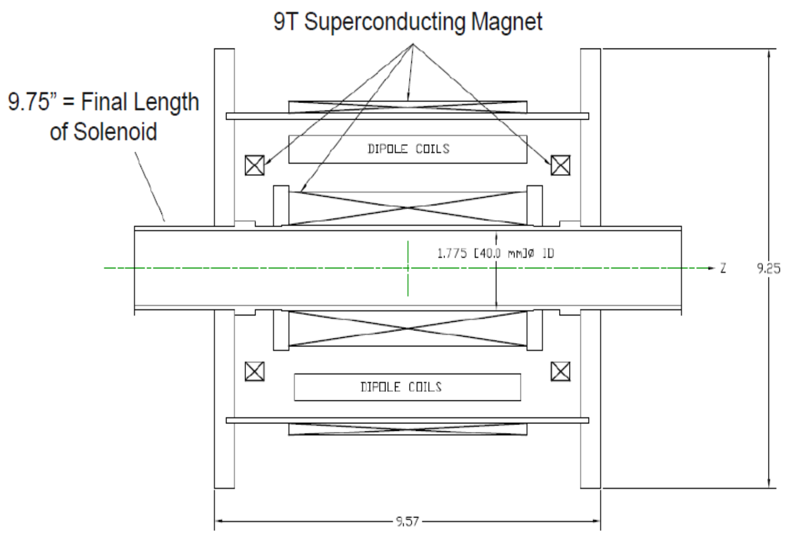
# Gas loads in PXIE

- With DP, and if we can achieve 3E-10 torr at front of CM
  - Flux to CM: Q=~$10^{-10}$ torr.l/s
  - d1=40mm, l1=400mm
  - One monolayer time: ~5000 hours




We are still in discussions with vendors. This geometry is not final.

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# Pumping Scheme

- $H^-$ Ion source ($10^{-5}$ torr)
  - Turbo pumps backed by mechanical dry pump with filter
- RFQ ($10^{-8}$ torr)
  - Turbo pumps backed by mechanical dry pump with filter
- MEBT ($10^{-7}$ torr), Diagnosis lines & beam dump
  - distributed ion pump + turbo pumps with filter@ absorber+differntial pumping near CM
  - achieve $10^{-10}$ torr where near CM
- Cryomodules ($<10^{-10}$ torr)
  - Beam vacuum, Pumped $10^{-7}$ by turbo pumps until cooled down (dry pump with filter)
  - Insulating vacuum: pumped down $10^{-4}$ by turbo until cooled, maintained by turbo as needs. Self-sustained$10^{-6}$ torr at cold.
  - Coupler vacuum: pump down by turbo and maintained with ion pump.
- All venting (except insulating vacuum) shall be slow and with filters.
  - control mas flow to <40 torr.l/s until pressure< 1 torr. according to DESY
  - Design venting locations so that particle migrates not toward CM
  - Controlled venting/pumping system with mass flow controllers currently being developed by NML

# Particle Free Vacuum Requirement

## Vacuum Requirement for MEBT to Assure SRF Survival

- Sharp metal particulate could destroy SCRF cavities
- Entire beamline should be particle free because of potential of particle migration (during pump down and vent-up)
- In practice, systems can have non-particle free components but trend is to remove them
  - CEBAF considering removal of sintered NEG because of shedding
  - XFEL has removed most TSP's

# Particle Free Handling & Assembly

## Vacuum Requirement for MEBT to Assure SRF Survival

- Low particulate vacuum handling and assembly practices should be employed for the entire beamline. Estimate ~4x more time than normal UHV installation. Special procedures include
  - all preassembly/assembly work done in Class 10 or 100 cleanrooms
  - open beamline work always to be done in a portable cleanroom
  - stricter gowning requirements
  - blow down all parts/hardware as being assembled according to procedure

# Absorber Risk to SCRF Cavities

## Vacuum Requirement for MEBT to Assure SRF Suvival

- Absorber is a danger to SCRF cavity by
  - Shedding of copper particulate
  - Close proximity to cavity (2m)
- Options to explore if absorber must be used:
  - Move it farther away from cryomodule (still risky due to particle migration)
  - Include fast acting gate valves protect in certain cases of catastrophic failure
  - Minimize line of sight to cavities to reduce chance that particles will be 'picked up' by flowing gas
  - Add pumping as close as possible to absorber to pull gas toward pumps and not sensitive surfaces
  - Add some sort of 'dust collector'
  - Continue investigating…

# Operational Concerns

- Dataloging the status of all vacuum devices, necessary for operation and analysis
- Interlocking fast valves at both ends of CM, but no much meaningful protection from vacuum failure within 10m, so low particulate vacuum practice shall apply on entire PXIE beamline
- Realtime RGA, try to detect slow leaks, R&D needs
- Gauging: double gauges shall be used to reduce access time and increase system reliability
- Operating procedures to reduce human errors, such never venting coupler vacuum when CM is cold, etc.
- Vacuum Training:
  - Human error is always major risks in Vacuum practice
  - Fermilab has not been used to low particulate UHV practice yet

# Operational Concerns

When we have no direct eyes on cold vacuum:

- No gauge at cold, but
  - Thermal transpiration: Knudsen relation at equilibrium molecular flow region

    $N_{cold}=(T_{warm}/T_{cold})^{1/2}N_{warm}$

    $P_{cold}=(T_{cold}/T_{warm})^{1/2}P_{warm}$
- Signal of pressure wave delays significantly due to condensation
  - Up to 40 hours at leak rate of $10^{-6}$ torr.l/s at 2K, as at DESY, So Cold leak might not be noticed until RF or Cryo reactions
  - d=4.3cm,L=75.3m

    $t=4.01\times10^{-2}Q^{-0.9595}$ @1.9K

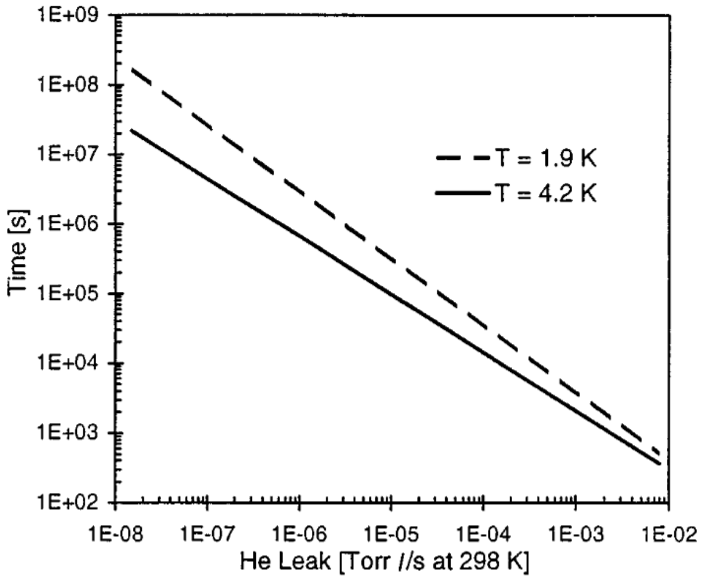


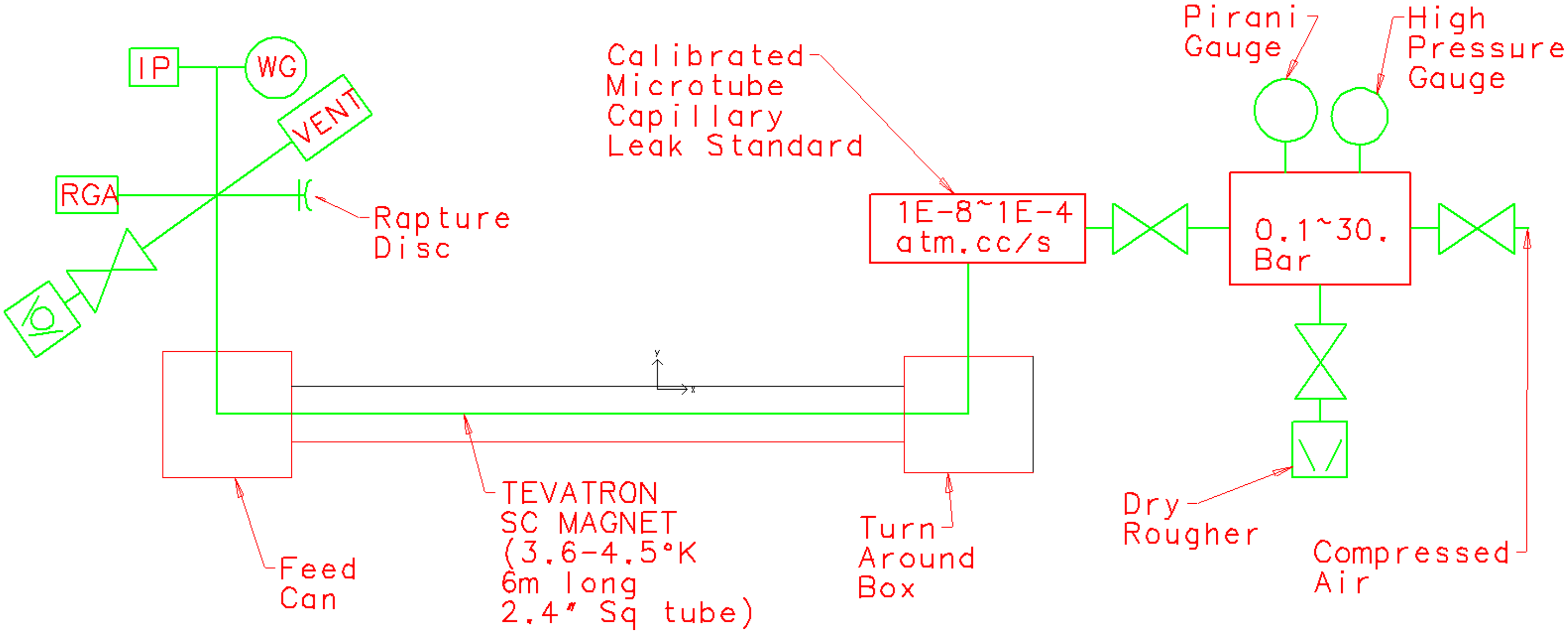

FIG. 6. Predicted time needed for the He pressure front to reach the instruments at the distant end with the cold bore tube at 1.9 and 4.2 K as a function of the leak rate in Torr ℓ/s at 298 K.

E. Wallen, J. Vac. Sci. Tech A15(6)1997

# R&D proposal: *realtime monitoring with RGA*

- slow leaks covered by huge cryo pumping of cavities, total pressure does not show problem
- Most experiment about cold leaks were done 15 years ago, and with total pressure gauge, $10^{-10}$~$10^{-11}$ torr
- modern RGA is much more sensitive and inexpensive now, $10^{-14}$~$10^{-15}$ torr partial pressures
- Changes of partial pressure ratio will indicate vacuum environment status evolving
- So, It may be possible to take preemptive measure before big failure occurs
- No isotherm data @1.8K for $H_2$, Air

# R&D proposal: realtime monitoring with RGA



# Summary

- Needs more input on vacuum requirement from SRF
- System shall be engineered to satisfy the requirement and cost effectively
- QC is critical for achieving a reliable vacuum system
- Preliminary calculation shown that necessary add differential pumping next to CM; $10^{-10}$ torr @CM entry is necessary
- work in near future
  - Calculate the pressure profile along beamline according to the lattice
  - Optimize the location and pumping scheme if necessary based on the pressure profile
  - R&D shall take place when engineering resource allocated

# Ref: recommended machining fluids

Relton A-9
Tap Magic
Tapmatic #1 or #2
"Pearl" Kerosene by Chevron Chem CO
"Tool Saver" by Do All Corp.
Cutzol EDM 220-30
Sunnen Man-852 Honing Oil
Vytron Concentrate
Rust-Lick G-25-J
Wheelmate #203
Aqua Syn 55 by G-C Lubricants CO
Cold Stream Coolant by Johnson Wax CO
"Acculube" by Lubricating Systems Inc.
Micro Drop "Advanced System Lubricant" by Trico
Micro Drop "New Vegetable Based" by Trico

Rapid Tap
Trim Tap
RD2-195
Dip Kool 868
DIP Kool 862
Dip Kut 819H
No Sul #6871
Kool Mist #88
Cimcool 5 Star 40
Cimperial # 1011
Haloform CW-40
Trim Sol
Trim9106CS
CINDOL 3102
PenWalt #DP 1131

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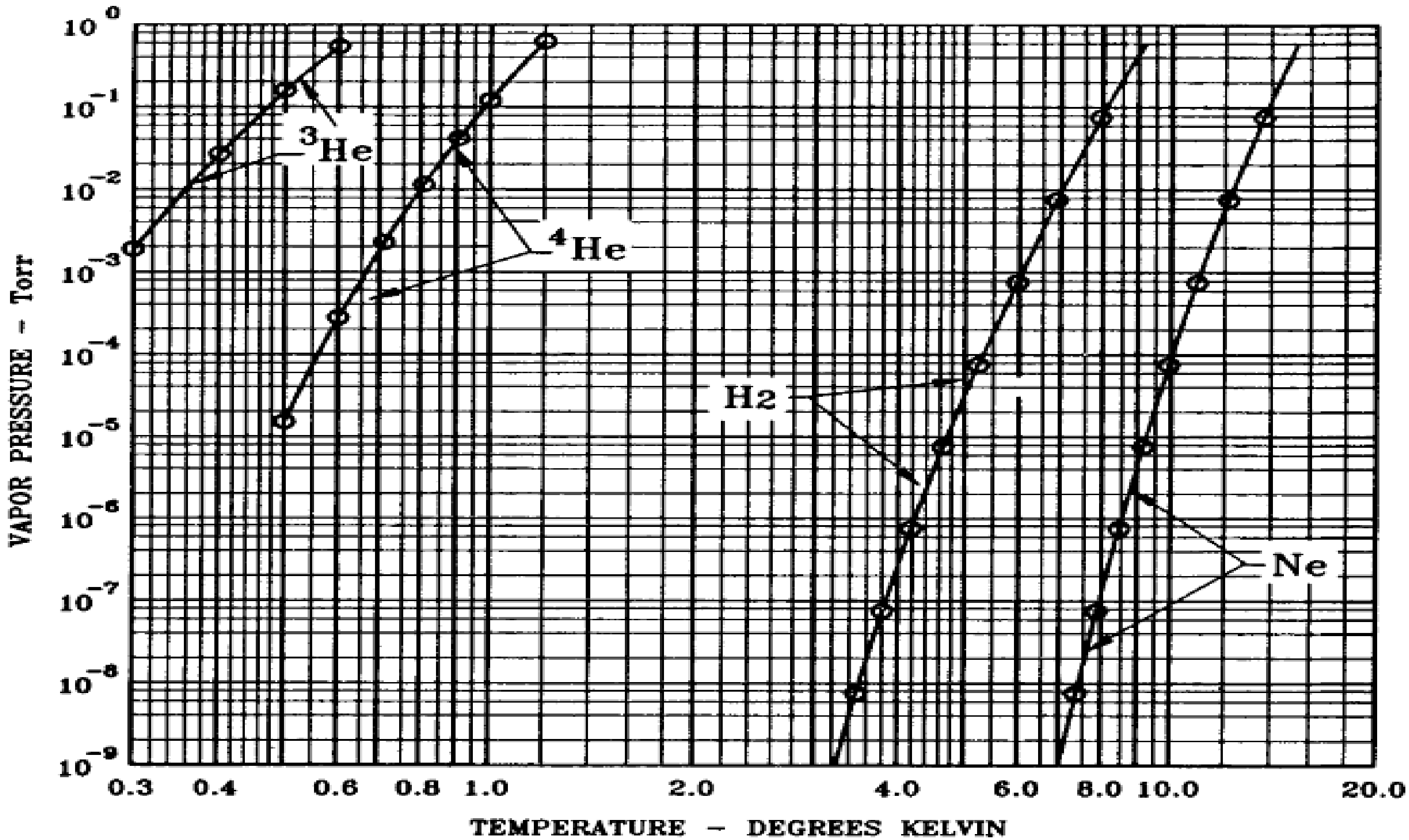
# Ref: Vapor Pressures of $H_2$, He



# Ref: Outgassing Rates of some materials

| Metals and Glasses | Desorption Rate (mBar-l/sec- $cm^2$ x $10^{-10}$) 1 hr @ vacuum | 4 hrs @ vacuum |
|---|---|---|
| Aluminum | 80 | 7 |
| Copper (mech. polished) | 47 | 7 |
| OFHC Copper (raw) | 266 | 20 |
| OFHC Copper (mech. polished) | 27 | 3 |
| Mild Steel, slightly rusty | 58,520 | 199 |
| Mild Steel, Cr plate (polished) | 133 | 13 |
| Mild Steel, Ni plate (polished) | 40 | 4 |
| Mild Steel, Al spray coating | 798 | 133 |
| Molybdenum | 67 | 5 |
| Stainless Steel (unpolished) | 266 | 20 |
| Stainless Steel (electropolished) | 66 | 5 |
| Molybdenum glass | 93 | 5 |
| Pyrex (Corning 7740) raw | 99 | 8 |
| Pyrex (Corning 7740) 1 mo. At Atm. | 16 | 3 |

Ref. "Modern Vacuum Practice", Nigel Harris, pg 240

# Ref: Hydrogen Isotherm

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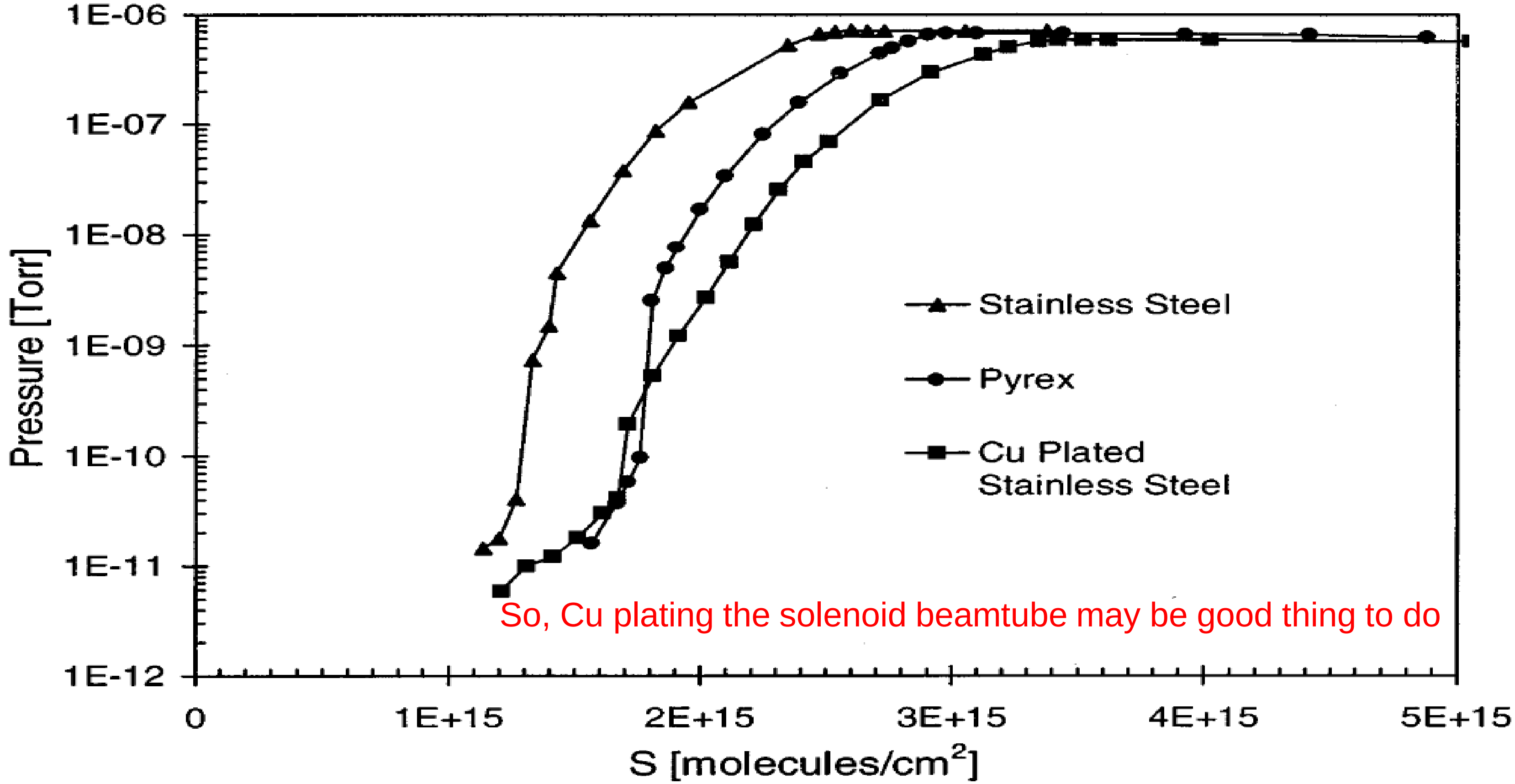


FIG. 2. $H_2$ adsorption isotherms at 4.2 K on Pyrex, stainless steel, and Cu plated stainless steel (Ref. 20).

# Ref: Helium Isotherm 1.9-4.2K

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